Trends in domestic electricity consumption in Botswana

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ABSTRACT

Data on electricity consumption patterns relating to different end uses in domestic houses in Botswana is virtually non-existent, despite the fact that the total electricity consumption patterns are available. This can be attributed to the lack of measured and quantified data and in other instances the lack of modern technology to perform such investigations. This paper presents findings from initial studies that are envisaged to bridge the gap. Electricity consumption patterns of 275 domestic households in Gaborone (the capital city of Botswana) have been studied. This was carried out through a questionnaire survey and electricity measurements. Households were categorized based on the number of people occupying the house. From the study, it was evident that the number of people influences the amount of energy a household use although this cannot be treated as an independent factor when assessing energy use. The study also indicated that heating, cooling and domestic hot water (DHW) account for over 30% of energy used in the home. This is worth considering in energy consumption reduction measures. Due to a small sample size, it would not be wise to draw sweeping conclusions from the analysis of this paper or to make statements that would be aimed at influencing policies. However, the results presented forms a formidable base for further research, which is currently on going.

KEYWORDS: *Botswana, Electricity consumption; Domestic; Monitoring, trends*

1 INTRODUCTION

Botswana is a country currently faced with a widespread dearth of electricity supply. This is mainly because Botswana depends largely on energy imports, which puts a strain on power security. Since 2008, Botswana has been importing more than 80% of its energy supply each year (Essah and Ofetotse, 2014) mainly from the power company Eskom, in South Africa (at least 70% imported). With countries that export energy to Botswana experiencing energy shortages of their own and cutting back on exported power, there is pressure for Botswana to generate its own energy. In light of this, plans have been underway for self-sufficiency in electricity supply. However, until the new power station (Morupule B) is fully operational, which is currently in question as there have been several unit failures since 2012, the country has to grapple with load shedding.

1.1. Structure of Power Company

Botswana's power company is autonomous (one state owned) in all its totality. Botswana power corporation (BPC) is the sole company responsible for generation, transmission and distribution of electricity in the country. The corporation comprises of two thermal power plants namely: Morupule A (132 MW capacity) and Morupule B (proposed estimate of 600 MW capacity). The source of fuel for both plants is coal, supplied from the adjacent Morupule colliery. The Morupule A power station has been in existence since 1986 and has reached the last stages of its useful life hence experiencing production challenges. Its operational capacity has been declining over the years reaching an all-time low of 40 MW in 2011 compared to 100 MW when it was commissioned. In 2013, Morupule A power station could only supply 1% of the country's energy supply (BPC, 2013). It is therefore critical that Morupule A is refurbished to restore it to its dependable capacity. Botswana has approved commencement of refurbishments as of 2013 and the Morupule A is expected to be back in operation by 2017 (BPC, 2013). While refurbishments are underway for Morupule A, Morupule B power plant has contributed significantly to the country's energy supply. In 2013, the plant contributed to 19% of the country's energy supply (BPC, 2013). However, although it is envisaged to have potential, this is not without challenges. The power plant's proposed installed capacity (600 MW) was to be commissioned in stages of 150 MW from 2012. In 2013, two units were commissioned and the other two were completed in 2014. Nevertheless, in October 2014 three units went out of operation due to technical problems that included boiler failures leading to shortage of power in the country. Therefore until the Morupule A plant in refurbished and Morupule B is fully operational, Botswana has to grapple with acute shortage of power, reliance on imports and rolling power outages.

During peak hours, which have been identified to be between 0600-1000hrs and 1800-2200hrs energy demand outstrips available supply (BPC, 2013). Therefore, BPC has resorted to scheduled load shedding to balance grid demand and supply. However, even with a well-documented load-shedding schedule in place, during times when localities energy demand exceeds 50MW, areas outside the load shedding schedule are also affected (BPC, 2013). Therefore, unexpected power cuts for many cities, townships and suburbs do occur on a daily basis. Of all the sectors of the economy (i.e. mining, commercial, government and domestic), the domestic sector (which contributes to 23% of the country's energy consumption on average) is mostly affected by the power cuts thereby affecting people's productivity. As a result, there is a great need for measures to be taken to identify possible solutions and manage the country's energy to reduce load shedding. In this instance, the first sector worth starting with is the domestic sector.

The national grid provides the majority of electricity in Botswana. However, plans are underway to provide non-grid electricity to remote and rural areas of the country where the costs of drawing electricity power-lines may be prohibitive. BPC has now collaborated with Electricity de France (EDF) and formed a private company- BPC Lesedi, which operates through a franchise model to provide renewable energy products and services. At the end of March 2013, BPC Lesedi was supplying and servicing 600 households with solar home systems accounting for a total installed capacity of 100kW (BPC, 2014a). This renewable energy initiative assists in providing power to remote and rural areas of the country. However, the vast majority of electricity supply in Botswana is still distributed by the national grid. Additionally, even though plans and strategies exist to increase the number of small isolated grids in rural areas; rural electrification is first and foremost a matter of extending the national grid. This means that the more households are connected to the grid the more pressure on the national grid to balance demand and supply for energy to be available to all.

To manage that which is available there is a noteworthy need for a comprehensive understanding of patterns of energy use in the domestic sector in an effort to promote conservation, efficient use, technology implementation and energy source switching (Swan and Ugursal, 2009). Understanding the trends/patterns of energy use in the domestic sector has a significant impact on energy management both regionally and nationwide. This is because the residential sector is characterised by prevalent morning and evening peaks, variable occupancy patterns and building structures that make it difficult to predict energy consumption of the sector (Rankin and Rousseau, 2008). Furthermore, energy consumption of other sectors is generally better understood because of their more centralised ownership, self-interest and expertise in reducing energy consumption (Swan and Ugursal, 2009). Other sectors also have high levels of regulation and documentation while the same cannot be said about the residential sector. Additionally, domestic electricity loads largely comprise of small number of appliances with mass penetration rates that require identification for load shifting and/or energy management (Finn et al., 2013). Zhang et al. (2012) ascertain that residential energy consumption is a complex issue highly related to the physical characteristics of homes in which people live, the electrical appliances within the homes and the occupancy behaviour of the energy users thereby making the sector of much interest to researchers. There is therefore a general interest in understanding the detailed consumption characteristics of the residential sector in an effort to promote conservation, efficiency, technology implementation and energy source switching more so in the case of Botswana.

This paper presents an initial study that attempts to develop an understanding of energy usage patterns in the Botswana domestic sector and how this usage impacts on the nation's total energy consumption. The study investigates current trends in electricity consumption in households in one city (Gaborone) through the analysis of a recent self-administered questionnaire survey. Gaborone has 231,592 people living in 74, 963 households. Altogether, results from 275 households (by no means representative of the whole Gaborone city) have been used in this study. The study plays a significant role in analyzing energy consumption in Botswana considering the lack of energy data. The aim of this work is to improve the current understanding of electricity consumption in Botswana domestic buildings, to identify the trends in consumption of different appliance groups and their possible impact.

2 HOUSEHOLD ELECTRICITY USE

A better understanding of energy consumption drivers has become an increasingly pressing issue all over the world and numerous attempts have been made to identify the drivers through different approaches. Among these is work by Wood and Newborough (2003) who identified micro-level activities such as the difference in the length of time taken to do an activity and the availability of appliances, age of a house and behavioural patterns as influential factors for energy consumption in households. This also accounts for why households with similar characteristics have different energy consumption profiles. Tso and Yau (2003) investigated how housing types (government subsidized home ownership scheme, private development, village house), household characteristics (age of the house, size of the house in square feet, household income, the number of household members) and appliance ownership (i.e. the type and number of appliances available in the household) influence energy consumption in households. The results of the study indicated that all factors investigated have significant effects on household energy consumption.

Firth et al. (2008) indicated that the type and number of appliances in the property, and the use of these appliances by the occupants generally influence energy consumption in households. In another study, O'Doherty et al. (2008) identified house value (price), household income, house age (year the house was built), dwelling type (detached, semi-detached), tenure (owned, rented), house location (city versus rural area), occupancy period (years lived in the house), household composition (age variation of occupants) and social status (e.g. semi-skilled, unskilled) to influence energy consumption either negatively or positively. In addition, Yohanis et al. (2008) identified size of the house (floor area), location, type of dwelling, age of the house, number of occupants, occupation (employed, students, retired), household income, age of the occupants and appliance ownership as factors that influence energy consumption. In their study, McLoughlin et al. (2012) ranked the factors that influence energy consumption according to the number of times they were cited in the literature they reviewed. Some of the factors identified by the authors include dwelling type (e.g. detached, semidetached), household income, age of the occupants, appliance holdings, number of occupants, location, household composition, appliance rating, floor area, time of use, weekday/ weekend, external/internal temperature, dwelling age, number of rooms, occupation/employment status, tenure type, disposable income and number of bedrooms among others. McLoughlin et al. (2012) used these factors to analyse the effect of dwelling, occupant characteristics and household appliances on total electricity consumption, maximum demand, load factor and time of use (ToU) of maximum electricity consumption. The results of which indicated a strong link between the parameters.

From the reviewed literature it can be concluded that there are several determinants of energy consumption in houses but the most commonly cited are location (city or rural), type (detached, flat, semi-detached), tenure type (owned, rented), size (number of rooms, number of bedrooms or floor area), household income, number of occupants, appliance holding and rating, household composition (age variation, occupation), day of the week (weekday or weekend), weather and behavioural patterns. It is therefore worth investigating how some of these factors affect energy use in Botswana households.

3 TYPE AND SOURCES OF DATA

National statistics provide annual totals of domestic electricity consumption often as avarage values. These statistics provide useful information on residential sector energy consumption at regional and national levels. However, they do not provide details of individual end-uses, such as energy consumption for space heating, cooling and other major residential applications. The more detailed source of energy consumption data in most countries is the billing records of energy suppliers which gives information of energy consumption of each dwelling on a monthly basis. However, overall energy consumption of a household alone without additional appliance consumption, economic and demographic characteristics information leaves a huge gap in any attempt to assess the energy use of the households (Swan and Ugursal, 2009).

In view of limitations of the data from various statistics sources, housing surveys have become very significant in an attempt to bridge the gap and provide detailed household information. These surveys usually target a representative sample of the population and typically attempt to determine the drivers of energy consumption. In addition, the surveys usually attempt to obtain the energy supplier’s billing data to correlate energy consumption of the households with their characteristics (Swan and Ugursal, 2009). Examples of surveys that have been conducted in some countries includes the National Survey of Housing Quality (NSHQ) in Ireland which was a study that obtained detailed information from a representative sample of over 40 000 households on characteristics of dwellings and their members (Watson and Williams, 2003). The Residential Energy Consumption Survey (RECS) in the United States conducted by the US energy department covered questions on housing type and size, demographic characteristics of the household occupants, the ownership and related information of all common gas or electricity operated appliances in the household. This survey is conducted on a quadrennial basis and has been used by Energy Information Administration (EIA) in their energy audits (EIA, 2009).

In most countries, the published government sources and survey results about energy use makeup useful databases, which can be used to assess and model energy use. Such information is non-existent in Botswana. To date the only information that is available about residential energy consumption in Botswana is the total annual consumption of the residential sector from the BPC annual reports (BPC, 2014a). The reports do not provide details of individual end-uses (such as energy consumption for space heating, space cooling, domestic hot water and appliances as well as other major applications) although these details are required for accurate and cost effective assessment of energy use. In addition, because of shortage of energy supply, the actual consumption does not reflect the demand. This is because supply shortages has led to rationing and or load shedding leading to unfulfilled demand and consumption figures reflecting demand, which is constrained by supply factors. It is therefore important that extensive surveys be carried out in countries without basic databases to bridge the information gap.

3.1 Energy Surveys and Energy Monitoring

Surveys form the bases of gathering disaggregated information on energy use however; they are limited due to data collection difficulties and cost hence it is imperative that the selected sample is highly representative of the population being surveyed. In addition, they can be highly subjective in that the outcomes are dependent on the recollection of the respondents, which may not necessarily be accurate. Therefore, to reduce the subjectivity of surveys and provide details that surveys are not able to provide accurately, energy monitoring is usually used. With this method, monitoring devices are placed on energy consuming devices within households to determine their component of the house energy consumption and their usage profile as a function of time. Energy monitoring does not by any means undermine the significance of surveys but are used to augment and substantiate information obtained from them.

Many studies have made use of monitored data for example Firth et al. (2008) conducted high-resolution 5-minutely measurements of household electricity consumption on 72 UK households over a 2 year period. In this research five minutely average values of photovoltaic (PV) system electricity generation, import of electricity from the grid and export of electricity to the grid were recorded by current and voltage sensors and pulsed output meters. The meters recorded over 200 000 data values for each individual household over the 2-year period and the data was downloaded using public telephone network. Yohanis et al. (2008) carried out electricity measurements in 27 households using half hour load meters installed in series with normal utility meters over a year (December 2003 to February 2004). Each meter had a mobile telephone unit that enabled remote downloading of stored electricity average load. Ueno et al. (2006) carried out end-use electric power and room temperature measurements every 30 minutes for nine residential houses in Kyoto, Japan. The monitoring component consisted of a load survey meter (EUM) that measures electric power consumption for each home appliance. The measured data was sent to the network control unit (NCU) through the distribution lines throughout the house. Data was then collected through telephone lines, every night by a computer in the authors' laboratory. Bagge and Johansson (2011) used data loggers to measure total building electric power consumption and water flow every 6 seconds over 5 days including weekend. The study was conducted in 72 Swedish apartments. . It would be noted that even with energy monitoring in place, all these studies conducted surveys in the form of questionnaires to determine the demographics and household composition of houses. For example, Yohanis et al. (2008) conducted a survey over more than 200 households in Northern Ireland before reducing the sample size (for the purpose of analyses) to a representative sample of 27 households for further investigation through electricity load measurements. Therefore, the combination of surveys and energy measurements is necessary to assess household energy use.

There are numerous methods of measuring electricity consumption, which is evidenced by the studies outlined above in which different electricity measuring methods were used. Firth et al. (2008) identifies two main approaches to measuring energy use which are whole house and individual appliances monitoring. Whole house measurements involve measuring the energy consumption of the entire house at a high resolution. Here metering hardware is placed on or near the circuit breaker or utility meter of the house. The metering device usually have three parts: a sensor which simply clips around the outside of one of the wires in an electric meter, a battery operated transmitter unit which sends the information picked up by the sensor and a battery or mains operated wireless display unit. Individual appliance monitoring involves placing metering hardware between a socket and the plug of the individual appliances or on a collection of appliances being measured. The meters then provide energy consumption of each appliance as a function of time either instantaneously or by storing the data for later retrieval.The only hurdle about this type of energy consumption measurement is that some major energy consuming appliances like the cooker and the electric water heater as in the case of this study are hard wired or use different plug styles than standardised household appliances which make it difficult to measure their energy consumption. One way of overcoming the huddle would have been to use a multivoice system as in the case of the UK household electricity survey (Zimmermann et al., 2012). However due to the prohibitive costs of the multivoice system and the need for electricians, in this study only whole house and individual appliance monitoring for appliances that could be plugged into monitoring devices were carried out.

4 METHODOLOGY

Due to the lack of data on energy consumption in Botswana, data was collated to develop a better understanding of the Botswana domestic energy usage patterns. Through self-designed questionnaires, a survey was conducted. Household surveys were followed by energy measurements of two houses to investigate the energy usage patterns in households and how these differ from variables gathered through questionnaires.

4.1 Household Surveys

Gathering data was between December 2013 to March 2014 and September 2014, lasting for four months in total. All together 400 questionnaires were administered in different localities of Gaborone and 290 were received back. Of the 290 questionnaires received, fifteen were discarded due to lack of completion leaving 275 fully completed questionnaires to be used for data analysis. It can be noted that the sample size for of this study is by no means representative of the total households in Gaborone. However, the study (which is ongoing) provides the foundation for substantial data gathering and understanding of the possible energy trends in households and possible challenges in collecting data. The study also formed the basis for further investigations, which are ongoing.

The questionnaire was designed with three main sections forming the focus for data collection. *Section 1* was designed to integrate basic but detailed information about households such as; house type, size (floor area) and income bracket. This was to assess how household characteristics would affect energy consumption. *Section 2* was designed to gather information relating to household occupants. This included the number of people in a house, number of adults and children, the ages of the occupants, occupation, gender and time spent at home excluding sleeping hours. The object of the section was to assess how occupancy behavior and household composition influence energy consumption. *Section 3* investigated appliance ownership, usage levels and model brand name as well as make. This was so that power ratings could be obtained by referring to the manufacturer's specification according to a master list of wattage information collected from various manufacturers. For ease of identification, nine categories of appliances were identified based on the purpose for which they are used and/or the room of the house in which they are used. Each category had sub-divisions that represent appliance components. Fig. 1 shows this categorisation and respective components. The figure was adapted from Essah and Ofetotse (2014) where six categories (brown, cold, cooking, wet, lighting, miscellaneous) were considered.

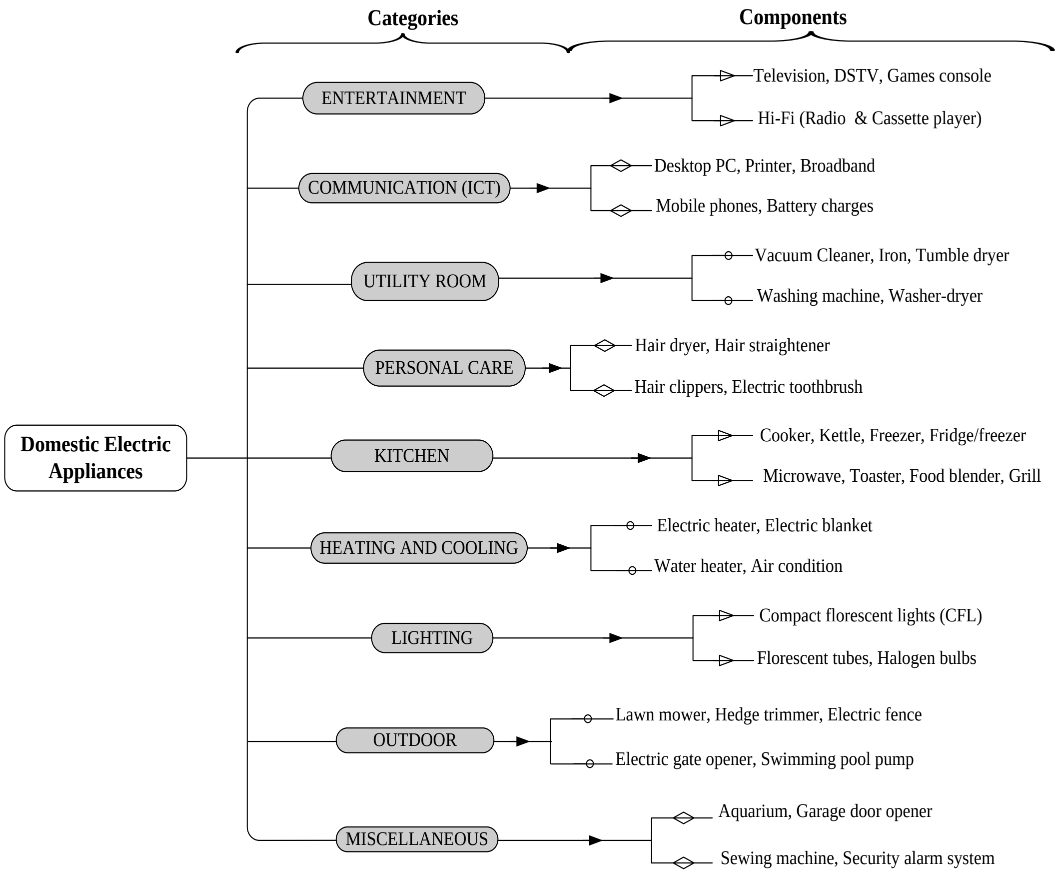


Fig. 1: Energy consumption appliance categories and some of their specific components (*Adapted from Essah and Ofetotse 2014)*

From the known categories and the data collated, electricity consumption of appliances was computed using Equation 1 (Essah and Ofetotse, 2014).

$$E_e = N_a \times A_r \times H_u \qquad (1)$$

Where:

- E_e= energy use per appliance
- N_a= the number of appliances (of same kind)
- A_r= the power rating of appliances in watts, usually given on the appliance itself
- H_u= the duration of an appliance usage in hours per week

Equation 1 is applicable to all categories of domestic appliances but for cold appliances, which includes refrigerators, freezers and combined fridge-freezer. This is because even though these appliances are in continuous use (i.e. switched on all the hours of the day) their compressors do not run continuously hence they do not draw a constant amount of power (Firth et al., 2008). In this regard, a standard usage that complies with manufactures' data was used.

For water heaters values from Eskom (n.d.) were used. According to Eskom (n.d.) if a 150 litres geyser is switched off for 15 hours a day, assuming it is set to 60 ℃, it will use an estimated 238 kWh of electricity over a month while a geyser that is kept on all day everyday (at the same temperature) uses approximately 342 kWh of energy a month. Therefore, as it would be expected a geyser that it kept on all day will use more energy than one that is switched off for extended periods in a day Eskom (n.d.). To determine how much energy a geyser would use, a simple Equation 2 for geysers that are turned off and Equation 3 for those that are kept on all day were used.

$$150x = 238y \qquad (2)$$
$$150z = 342q \qquad (3)$$

Where **x** and **z** are the energy consumption values in kWh to be computed while ***y*** and ***q*** are 100, 150 or 250 litres depending on the capacity to be computed.

Assumptions

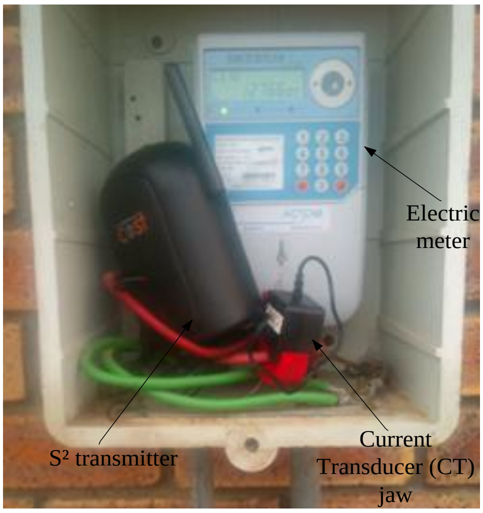
Due to the lack of data on energy consumption and household occupancy in Botswana, it is necessary to make assumptions for some scenarios. These were:

- Holidays and weekend load profiles are equalised to those for the weekdays for calculation simplicity
- Household would not change the stock of their energy using equipment during the year under investigation.
- Efficiency of appliances were not considered when carrying out the calculations
- All water heaters (geysers) are assumed to have a set temperature of 60℃. Increasing the thermostat temperature increases energy consumption. For example increasing the thermostat temperature from 60 ℃ to 70 ℃ will increase energy consumption by 5%.

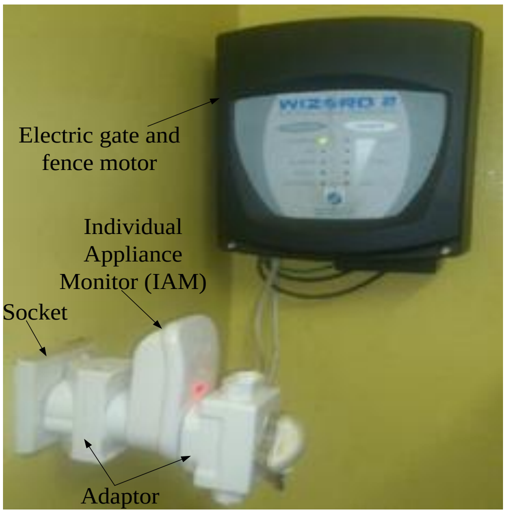
4.2 Household Electricity Consumption Measurements

In addition to questionnaire survey, the electricity usage in two homes was monitored using current cost monitoring devices (EnviR monitor and Individual Appliance Monitors (IAMs)). The monitoring was to determine the appliances component of the house energy consumption, the variability in their consumption and their usage profile as a function of time and to understand the possible challenges that would be encountered when monitoring is rolled out on a larger scale.

The EnviR monitor in conjunction with individual appliance monitors (IAMs) is able to monitor up to nine individual appliances in a household with the tenth channel logging the energy consumption of the whole house. In the case of this study, hourly energy consumption of the whole house and six individual appliances were measured over just less than three weeks during a hot December month 2013.



(a)



(b)

Fig. 2: Energy consumption monitoring set up
(a) meter box with the measuring instruments
(b) Electric fence and gate motor

Fig. 2a shows a typical meter box in Botswana with the current cost S^2 transmitter and current transducer (CT) jaw clipped on to the meter to measure whole house energy use. An illustration of one of the appliances plugged into the IAMs is shown in Fig. 2b. One significant hurdle that was worth overcoming was the wall sockets. Households in Botswana use the type M plug (which has three round pins in a triangular pat tern) and the type G electrical plug (which has three rectangular blades in a triangular pattern) concurrently. Nonetheless, the majority of households are now changing most if not all their socket plugs to type M to fit most appliances. Therefore, for the monitoring to take place two socket adaptors were required as indicated in Fig. 2b. It would be noted that monitoring took place over a hot December month hence it would be worth conducting measurements during a cold winter month to compare differences (if any) in usage profiles. For this study, since only two houses were monitored, no conclusions can be drawn from these measurements results; however, the results do reflect what was observed from the questionnaires. Significantly, it demonstrates that with more data, effective conclusions would be deduced from the study.

5 RESULTS AND DISCUSSION

5.1 Demographic Variables

The demography of the 275 sampled homes is shown in Table 1. The data gathered included the type of building, number of bedrooms, number of occupants, ages, gender and employment status. The observations made in this study are reflective of the 2011 census results for Gaborone (CSO, 2011) nevertheless; the argument still stands whether the sample size of 275 is representative. The observations also inform the ongoing study where the sample size is envisaged to grow. For example, about 75% of the population in Gaborone is aged between 14 - 64 years, while about 20% are between 0-14 years and less than 5% is 65+. There were more people within the 14 - 64 age range in the study and less people in the other age brackets more so the 65+ age which had 15 people. There were more detached houses than other house types which is reflective of the 49% detached houses in Gaborone (CSO, 2011). The larger number of people in full time employment is reflective of the more people in the working class age bracket in this study as well as from the 2011 census. Considering the fact that there were more 5 and 6+ person households from this survey, it cannot be inferred how this compares with census results since the census does not provide details of such information for Gaborone. There were more three-bedroom households than other categories as with the number of people in a house this cannot be inferred from the census results. Other demographic variations such as area of the house and income of the household though were part of the survey have not been included in this study because of the sensitivity of the data gathered.

To manage the effect of the multivariate on the analyses, it would be noted that for this study household size and energy consumption were the two variables being analysed with a view to engage with other variables in future analysis. Although analysis was based on household size, all other demographic variables, also significantly influence energy consumption in households as supported by Tso and Yau (2003); O'Deherty et al (2008); Yohanis et al. (2008); McLoughlin et al. (2012). Therefore, going forward the influence of other demographic variables as well as behavioral characteristics on energy consumption of Gaborone households will be factored into the analyses.

Table 1: A summary of demographic characteristics of the surveyed households

	GABORONE
AGE	
0-6	185
7-18	277
19-35	358
36-64	365
65+	15
All ages	**1200**
GENDER	
Male	538
Female	662
All genders	**1200**
OCCUPATION	
Student	404
Pre-school	108
Part time	85
Full time employment	388
Unemployed	62
Homemaker/ Nanny	62
Retired	31
Other	60
Total number of occupants	**1200**
HOUSEHOLD TYPE	

	GABORONE
Mixed	0
Traditional	0
Detached	150
Semi-detached	31
Town house	72
Apartment	11
Part of a commercial building	0
Mobile home	0
Shack	0
Rooms only	11
Total number of households	**275**
HOUSEHOLD SIZE	
1	26
2	30
3	32
4	37
5	75
6^+	75
All household sizes	**275**
NUMBER OF BEDROOMS	
1	19
2	26
3	196
4	26
5	8
6^+	0
Total number of households	**275**

5.2 Household Energy Consumption

The energy consumption results from the questionnaire are presented in this section. Considering the multivariate strands, a hierarchy cluster method using the Matlab platform was developed. The hierarchy method clustered the households by household size and their total yearly energy consumption. Hence, the two key variants: household size and total energy consumption were further analysed in the study. Fig. 3 shows the distribution of annual energy consumption per household category obtained from 275 surveyed houses. The categories for household sizes range from single person household to household sizes with six persons or more. There were more 5 and 6^+ households from the survey results hence their distribution range is wider. From the scatter plots in Fig. 3, it is obvious that the number of people in a house influences the amount of energy used. Energy values increased with the number of people in a household; 1-person households had the lowest energy consumption values, followed by 2-person, 3-person and 4-person. This conforms to patterns identified in studies by Yohanis (2012) who stated that there is a consensus that the number of people in households influences energy consumption that is, the more people there are the more energy would be consumed. Nevertheless, it was interesting to note that the households with more people (6^+ persons) did not necessarily use more energy (Fig. 3), 5 person households seemed to have higher consumption values than 6^+ person households which led to their average being higher (7468 kWh) than that of 6+ households (6473 kWh) as observed in Table 2. This can be explained by the fact that the number of people in a house is not a stand-alone factor in energy consumption. A household may have 6^+ people who are all in full time employment which means during hours when a house is not occupied energy consumption is very low. Likewise, if a household has four people all spending most days at home energy use is likely to be high. Other factors that play a part are the type and number of appliances available in a house (see Section 5.3).

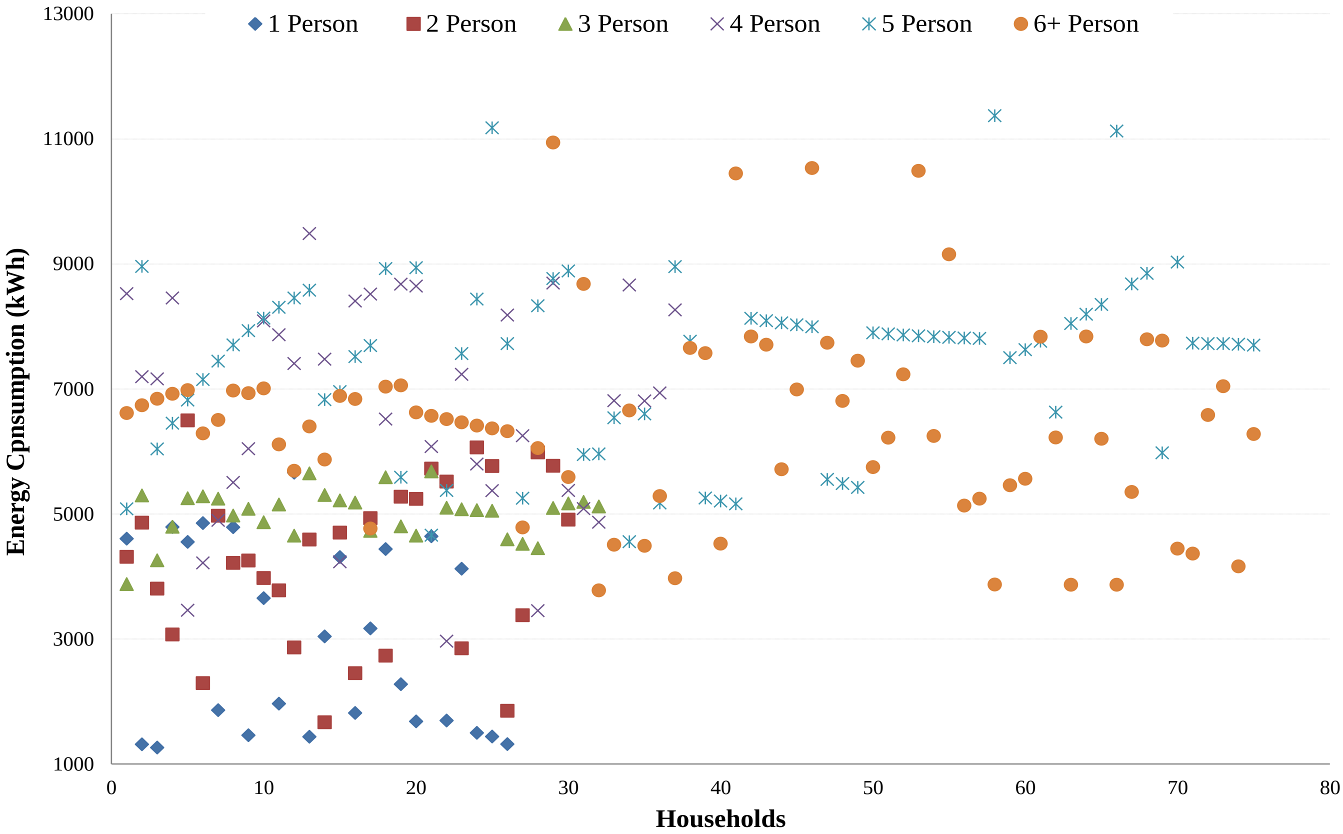


Fig 3: Energy consumption per household category

Using the clustered variants and SPSS (a statistical package), a statistical analysis of the results was performed. Many statistics inferences require that a distribution be normal or nearly normal. A normal distribution has skewness and excess kurtosis of 0, so if the distribution is close to those values then it is probably close to normal. As would be seen in Table 2, the skewness is between 0.2 - 0.5 but for the 5 person household which is close to normal (0.09). This range illustrates the fact that the results are not close to normal affirming the varied range of energy usage observed in Fig 3 and Fig 4.

Table 2: Summary statistics results considering clustered variants of energy use and household sizes

Statistics						
	1 Person	**2 Person**	**3 Person**	**4 Person**	**5 Person**	**6+ Person**
N	**26**	**30**	**32**	**37**	**75**	**75**
Mean (kWh)	2987	4277	4999	6692	7468	6473
Std. Error of Mean	294	245	69	286	165	178
Std. Deviation	1497	1341	391	1740	1432	1544
Skewness	0.25	-0.33	-0.76	-0.47	0.09	0.65
Std. Error of Skewness	0.46	0.43	0.41	0.39	0.28	0.28

Minimum (kWh)	1261	1666	3879	2965	4555	3777
Maximum (kWh)	5660	6495	5679	9486	11370	10940
Sum (kWh)	77654	128308	159958	247612	560067	485457

For a detailed investigation of the variation in energy use per household, Fig.4 illustrates the distribution patterns that were obtained from the SPSS analyses (summary in Table 2). As with Fig 3, Fig 4 also shows the influence of household size on energy use. 1-person households' energy distribution was between 1000 kWh and 6000 kWh per annum, 2-person households range between 1500 kWh and 6500 kWh. Although the mean energy consumption for three person households is higher than the 1 and 2 persons their range was within the limits and not extremely different. For example, the highest energy consumption was 5679 kWh whereas some 2-person households had a consumption of 6495 kWh. The consumption range increased for four and five person households but was observed to be lower for 6+ houses. This indicates that although it is expected that the more people in a house the more energy consumption there would be, it is not always the case due to factors mentioned above.

Significantly, the survey results demonstrate that, the average energy consumptions per households for all the 275 households is representative of other countries. The average energy consumption for Gaborone based on this study is 5482 kWh, which falls within UK values (4170kWh) according to DECC (2014). The Botswana value is higher than UK because the UK value is at a national level while the Gaborone one is at a city level with a small sample size. Therefore, it is expected that with the increase in sample size that average consumption value would decrease and the average energy consumption can be stated accurately.

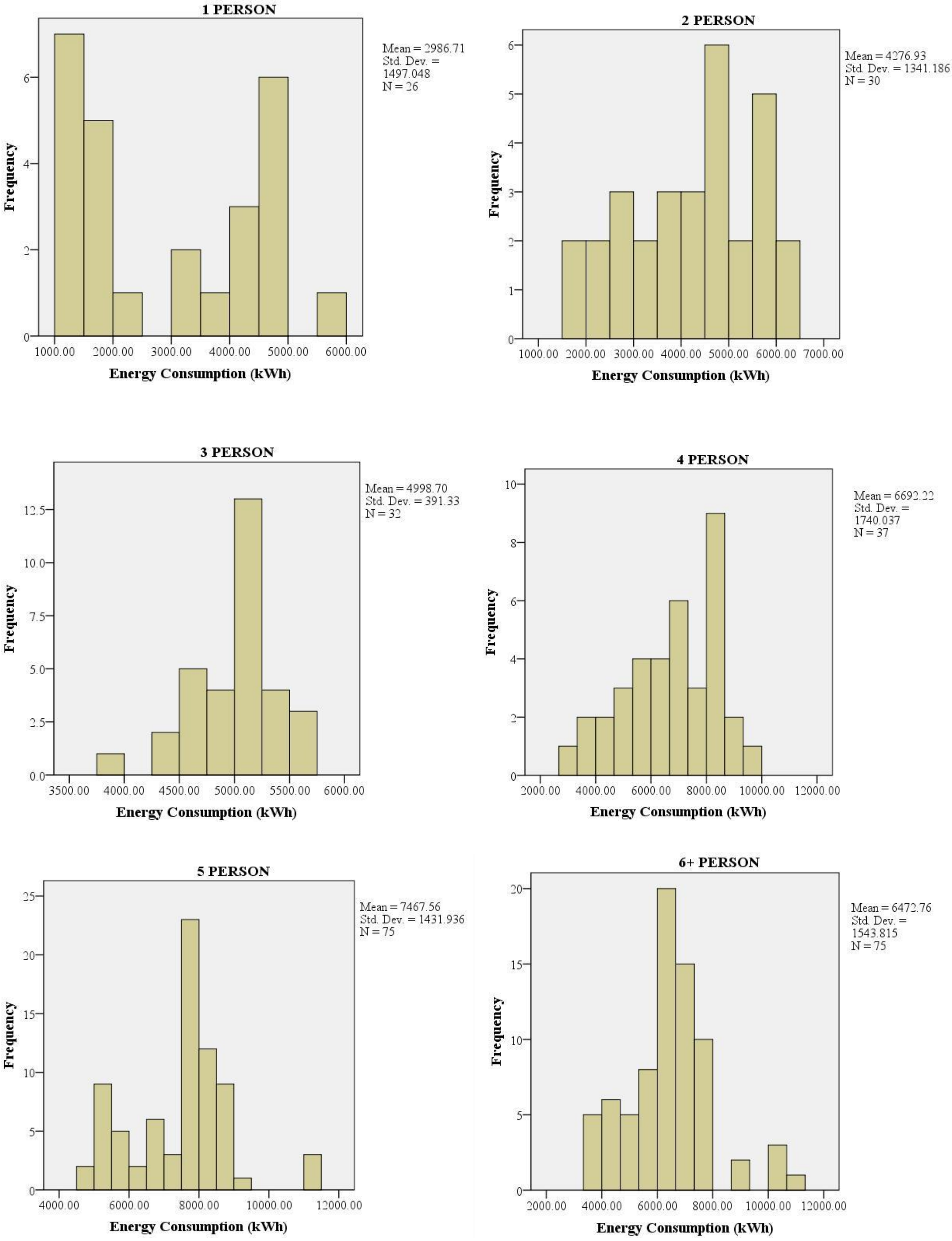


Fig 4: Energy consumption frequencies per household type

5.3 Domestic Appliances

Generally, the increase in electricity consumption within households is partly due to the type of appliances present in the household and how they are used. Some appliances use less than a kilowatt hour per day while others use several kilowatts a day. Nonetheless, appliance usage in general results in large demands of electricity. When demands from several appliances occur at the same time they can produce a peak demand of several kilowatt hours (Wood and Newborough, 2003). It is hence necessary to identify the appliances that cause the largest and the lowest peaks in demand within the home and their drivers in efforts to make informed decisions with regard to energy consumption reduction and load shifting.

5.3.1 Appliance ownership

The number and type of appliances present in a household influence the overall amount of energy a household uses. Fig. 5 shows a summary of appliances and their ownership levels based of 275 households of this study. The appliances indicated in the figure are not all appliances that were part of the survey, only those appliances with significant ownership level and energy consumption have been indicated. It can be deduced that there are necessary appliances for day-to-day living comfort such as television sets, cell phones and refrigerators. As it can be observed from Fig.5 these are in high possessions than other appliances. Households may possess multiples of one appliance although this has not been indicated in Fig.5. The total number of appliances present in households ranged from 9 to 40 excluding lighting. Lights are in greater possession in households. Nonetheless, not all the lights are used every day but are only used when required. Therefore, even if a household possesses a high number of lights it does not necessarily mean that its energy consumption will be higher.

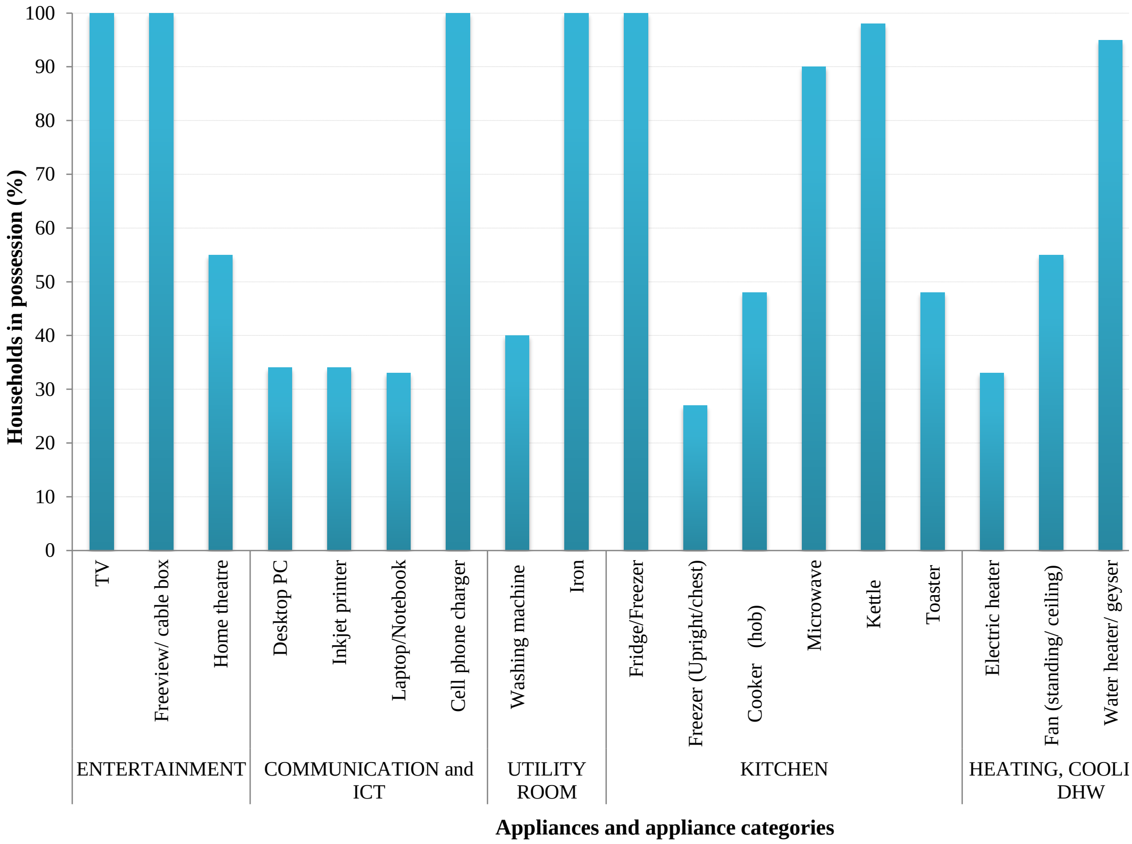
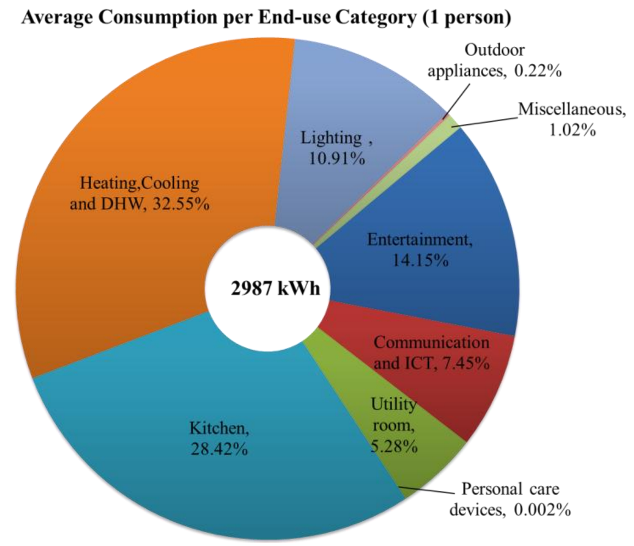
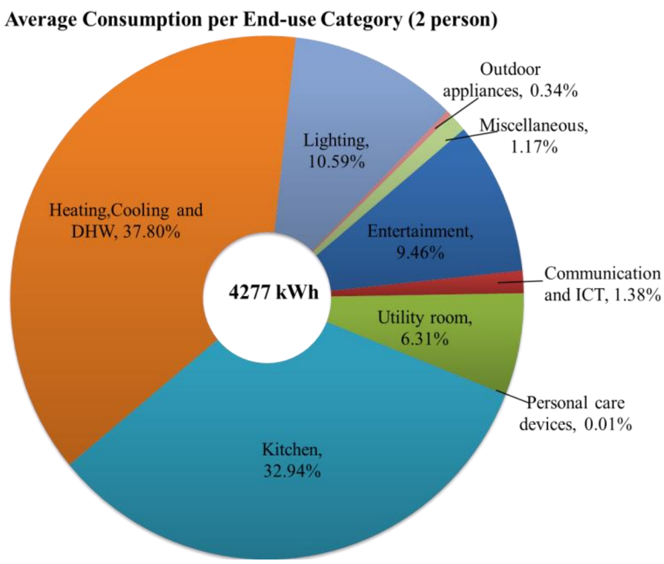


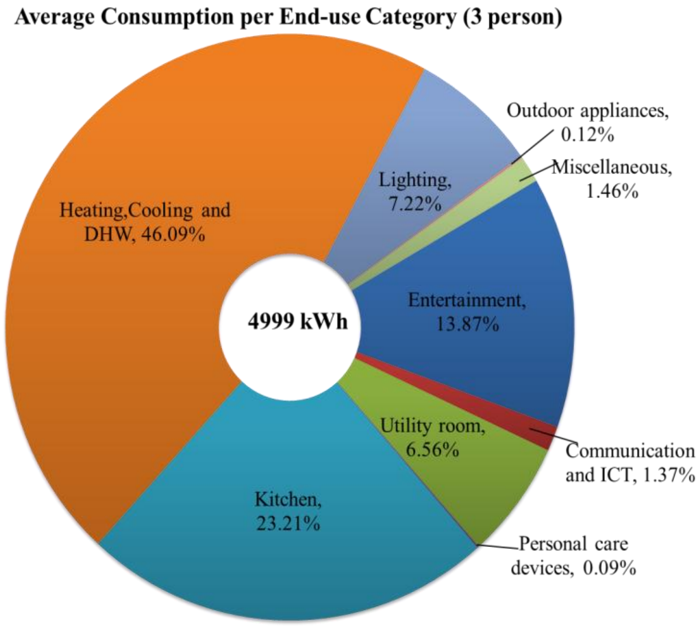
Fig 5: Ownership of appliances in surveyed households

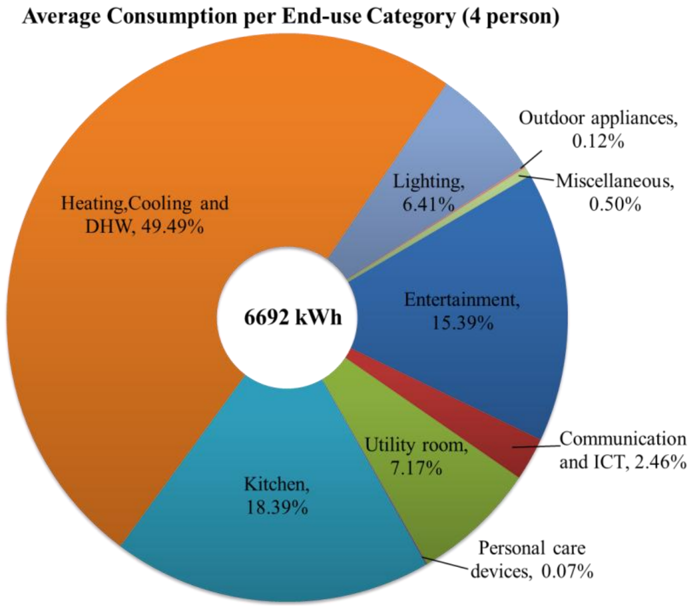
5.3.2 Appliance Energy Consumption

Fig.6 shows the percentage consumption of different appliance categories as a proportion of the mean energy consumption for each household category. It can be observed that heating, cooling and domestic hot water (DHW) contributes to more than a third of energy consumption for each household category. This includes portable heaters, fans, air conditioning and geysers as shown on Fig.5. According to Eskom (n.d), geysers are responsible for 30-50% percentage of energy usage in the home. This study supports this as more than 75% of the heating, cooling and DHW was made up of consumption from geysers. This was followed by air conditioning. However, because the ownership of air conditioning was low (30%) the overall energy consumption was low compared to geysers. Kitchen appliances also contribute significantly to energy consumption in the home. Energy consumption and ownership of personal care devices is almost negligible. Energy consumption and ownership of miscellaneous and outdoor appliances is also very low. These categories included security alarms, sewing machines, hair dryer, hair clipper, lawn mower, hedge trimmer, which are not the most popular appliances in the home their ownership levels ranged between 0.5 - 5%.






Average Consumption per End-use Category (3 person)
Outdoor appliances, 0.12%
Miscellaneous, 1.46%
Lighting, 7.22%
Heating,Cooling and DHW, 46.09%
4999 kWh
Entertainment, 13.87%
Utility room, 6.56%
Communication and ICT, 1.37%
Kitchen, 23.21%
Personal care devices, 0.09%


Average Consumption per End-use Category (4 person)
Outdoor appliances, 0.12%
Lighting, 6.41%
Miscellaneous, 0.50%
Heating,Cooling and DHW, 49.49%
6692 kWh
Entertainment, 15.39%
Communication and ICT, 2.46%
Utility room, 7.17%
Kitchen, 18.39%
Personal care devices, 0.07%

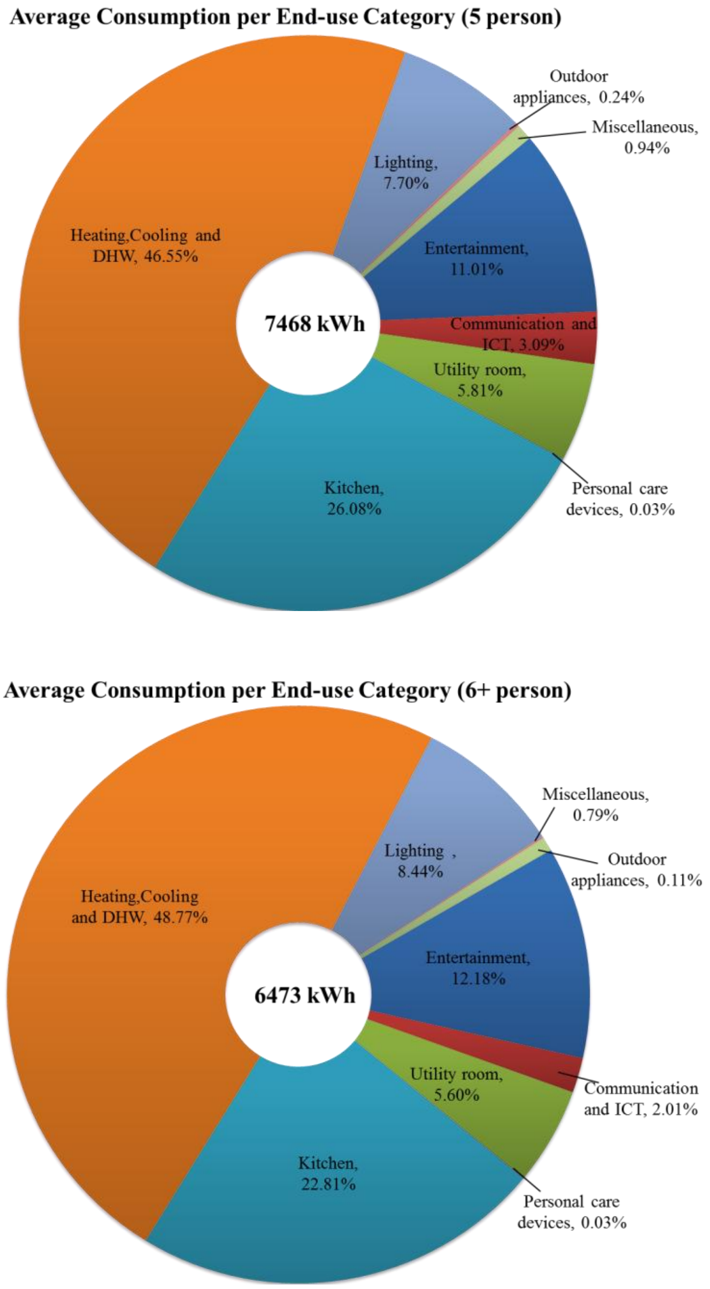
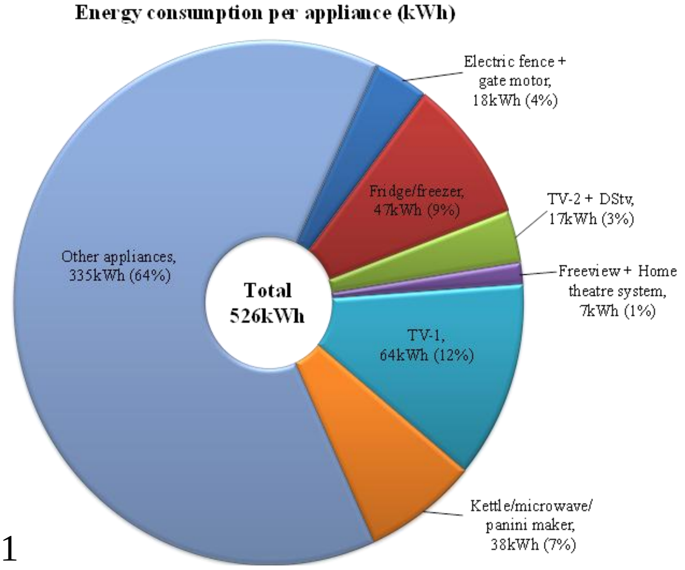


Fig 6: Propotion of energy consumption per end use category

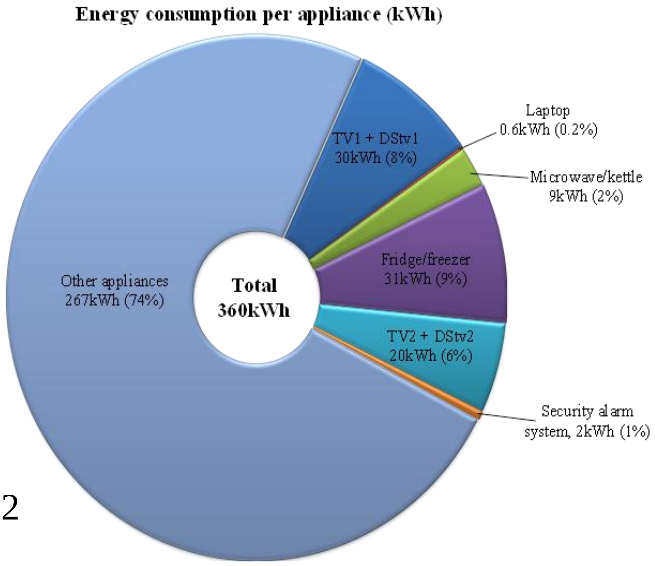
5.3.3 Appliance Energy Monitoring

Energy monitoring of specific appliances was carried out, the results of which are illustrated in Fig 7 and 8. Fig. 6 and Fig. 7 show ownership of appliances and the share of consumption over the monitoring period. Other appliances seem to account for a larger proportion of energy consumption in both households. These include cookers, lighting, hot water geyser, washing machines, phone chargers and all other appliances that were not measured. Some of the appliances like geysers and cookers could not be plugged into IAMs since they are hardwired making it difficult to accurately measure how much energy they use over a period or to derive their energy usage profiles. Consequently, clamp on devices are currently being explored in the ongoing research for such appliances energy consumption to be accurately measured. From Fig 6 it was observed that heating, cooling and DHW make up a large amount of energy consumption in the home therefore, it can be inferred that they constitute the majority of energy consumption of other appliances in Fig 7.

From Fig 7, it can be observed that no two households can exhibit the same consumption profiles even if they have similar characteristics. For example both monitored houses were 5 person households with two adults in full time employment, two school going children and a nanny. The households also had the same type of house (detached) and similar type of appliances. This is to be expected and attributable to many factors that include economic and behavioural factors, which are unique to each household and not discussed in this study. These differences affect use of appliances hence energy in households. It is therefore important that the differences in these factors are considered when analysing and making comparisons of energy consumption.



House 1



House 2

Fig. 7: Share of energy consumption by appliance type for house 1 and 2

Due to the fact that some of the monitoring took place in December, the consumption of appliances in these households may not be representative of typical weeks. More TV was watched that is, close to 15% of the total energy consumption for 2 TVs per house, which could be because occupants spend most of the day at home and could stay late watching TV. The fridge consumption was significantly high (9%) which could be because a lot of meal preparation was carried out during the December month which is not representative of the rate at which meal preparation will take place during other months. In December the household composition of most houses change, activities also vary compared to other times of the year hence no stable pattern of consumption can be established. In addition, two household do not provide a general overview of usage profiles in all households of the city. However, they do form a base to identify and in some instances understand the complexities and variables that are associated with monitoring household energy use in Botswana, a country without basic data on energy use.

6 CONCLUSIONS

Almost a third of the energy in Botswana is consumed by the domestic sector. This consumption depends on a number of interrelated engineering and human behavioural factors. There are two broad issues to be addressed: the first is to improve the efficiency of energy generation and reduce the energy consumed by electrical and mechanical appliances; and the second is to change the energy behaviour of householders. The results presented in this study although involved a relatively small number of dwellings provide a fundamental base to assess energy consumption in the Botswana households. From this study, key areas of energy consumption in the home were evident and presented in the following conclusions.

- Energy consumption increases with the number of people in a house although this is not always the case. Some households with more people do not necessarily use more energy even though literature suggests that the more people there are in a house the more energy would be used. The result is interesting and less compliant with literature. From this it can be concluded that number of people in a households may not necessarily be an indicator, (in isolated conditions) to determine energy consumption of a household. Other factors such as ownership and use of appliances play a fundamental role.
- Energy consumption for heating, cooling and DHW make up more than a third of energy consumed in Botswana households as evident in this study. This information is significant in efforts to encourage consumers to reduce their energy use.
- Households exhibit different energy profiles due to lifestyles and appliance ownership that are unique to every household.

From the study, the results presented give a valuable base for identifying energy load profiles over different seasons. However, since the study is an initial study to understand energy use in Botswana households it would not be wise to draw sweeping conclusions from the analysis or to make strong statements concerning policies to reduce energy consumption in households. The study does however, support observations made by other authors that there is a growing demand for electricity in the domestic sector that warrants attention. The results presented in this study also helped indicate that understanding the characteristics of households and their appliance usage are a useful area that when addressed can help influence energy conservation to reduce the acute power shortage that Botswana is currently facing. It also came to light that the combination of measured data with quantitative data surveys of appliance ownership such as in the study helps in understanding the drivers of appliance usage. As it is an initial study to understand energy use in Botswana, it is understandable that more data is required for authors to find a general energy consumption pattern. The ongoing research will further expand on this study to improve the current understanding of electricity consumption in Botswana households and to identify the trends in consumption of different end use groups.

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REFERENCES

Amato, A. D., Ruth, M., Kirshen, P. and Horwitz, J. , 2005. Regional energy demand response to climate change: methodology and application to the commonwealth of Massachussetts. Climate change, 71, pp. 175-201.
Botswana Power Corporation (BPC), 2013. Load shedding information. http://www.bpc.bw/Pages/load_shedding.aspx. (Accessed 15 February 2014)
Botswana Power Corporation (BPC), 2014a. Annual reports. http://www.bpc.bw/Pages/annual_report.aspx. (Accessed 15 May 2014).
Botswana Power Corporation (BPC), 2014b. Electricity tariffs. http://www.bpc.bw/Pages/tariffs.aspx (Accessed 15 May 2014).
CSO, 2011. Statistics brief 2011. http://www.cso.gov.bw/templates/cso/file/File/BCWIS%20_Poverty_%20Survey%20Statsbrief%20Nov%202011..pdf (Accessed 12 August 2013).
DECC, 2014. Energy consumption in the UK. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/338662/ecuk_chapter_3_domestic_factsheet.pdf. (Accessed 15 February 2015).
Energy Information Administration (EIA), 2009. Residential Energy Consumption Survey (RECS).
Eskom (no date). Managing your geyser for a more energy efficient future. http://www.pcb.org.za/upload/files/EskomGeyserFactSheet.pdf (Accessed 10 October 2013).
Essah E. A., and Ofetotse E. L. , 2014. Energy supply, consumption and access dynamics in Botswana. Sustainable Cities and Society, 12, pp. 76-84.
Finn, P., O'Connell, M. and Fitzpatrick, C., 2013. Demand side management of a domestic dishwasher: Wind energy gains, financial savings and peak-time load reduction. *Applied energy*, 101, pp. 678-685.
Firth, S., Lomas, K. and Wall, W. R. , 2008. Identifying trends in the use of domestic appliances from household electricity consumption measurements. Energy and buildings, 40 (5), pp. 926-936.
McLoughlin, F., Duffy, A. and Conlon, M., 2012. Characteristics domestic electricity consumption patterns by dwelling and occupant socio- economic variables: an Irish case study. Energy and buildings, 40, pp. 240-248.
Mmegi, 2014. Morupule B breaks down againhttp://www.mmegi.bw/index.php?aid=46529. (Accessed 15 November 2014)
O'Doherty, J., Lyons, S. and Tol, R., 2008. Energy-using appliances and energy saving features: determinants of ownership in Ireland. Applied energy, 85 (7), pp. 650-662.

Pardo A., Meneu V. and Valor E., 2002. Temperature and seasonability influences on Spanish electricity load. Energy economic, 24 (1), pp. 55-70.

Parti, M. and Parti, C., 1980. The total and appliance-specific conditional demand for electricity in the household sector. *The Bell journal of economics*, **11** (1), pp. 309-321.

Rankin R. and Rousseau, P. G., 2008. Demand side management in South Africa at industrial residence water heating systems using in line water heating methodology. Energy conversion and management, 49 (1), pp. 62-74.

Ren, Z., Paevere, P. and McNamara, C., 2012. A local-community-level, physically-based model of end-use energy consumption by Australian housing stock. *Energy policy*, **49**, pp. 586-596.

Swan, L. G. and Ugursal, V. I. , 2009. Modelling of end-use energy consumption in the residential sector: A review of modelling techniques. Renewable and Sustainable Energy Reviews, 13(8), pp. 1819-1835.

Tso, G. K. F. and Yau, K. K. W., 2003. A study of domestic energy usage patterns in Hong Kong. Energy, 28 (15), pp. 1671- 1682.

Ueno, T., Sano, F., Saeki, O. and Tsuji, K., 2006. Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data. *Applied Energy,* **83** (2), pp. 166-183.

Watson D. and Williams, J., 2003. Irish national survey of housing quality. Dublin: the economic and social research institute.

Wood, G. and Newborough, M., 2003. Dynamic energy consumption indicators for domestic appliances: environment, behaviour and design. *Energy and Buildings*, **35** (8), pp. 821-841.

Yohanis, Y. G., 2012. Domestic energy use and householders' energy behaviour. Energy Policy, 41, pp. 654-665.

Yohanis, Y. G., Mondol, J. D., Wright, A. and Norton, B., 2008. Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic energy use. Energy in buildings, 40 (6), pp. 1053-1059.

Zhang, T., Siebers, P. and Aickelin, U., 2012. A three dimensional model of residential energy consumer archetypes for local energy policy design in the UK. *Energy policy*, 47, pp. 102-110.

Zimmermann J., Evans, M., Griggs J., King N., Harding, L. and Roberts, P., 2012. Household electricity survey: a study of domestic electrical product usage. Intertek testing and certification Ltd. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/208097/10043_R66141HouseholdElectricitySurveyFinalReportissue4.pdf